A comparison of two ensemble generation methods based on oceanic singular vectors and atmospheric lagged initialization for decadal predictions

MiKlip Project – Module A (WP: A Coordination)

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Motivation: toward reliable decadal climate predictions

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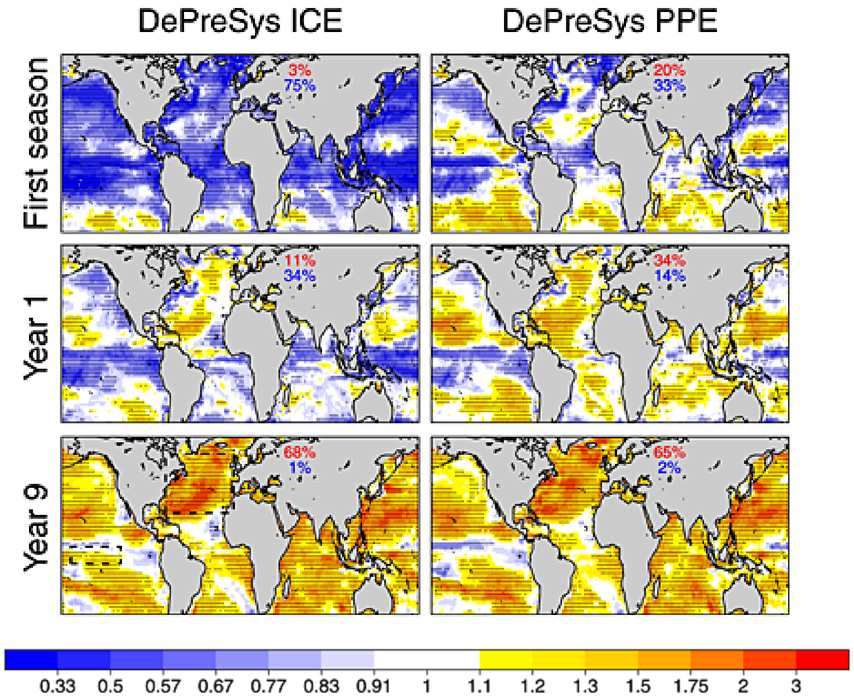
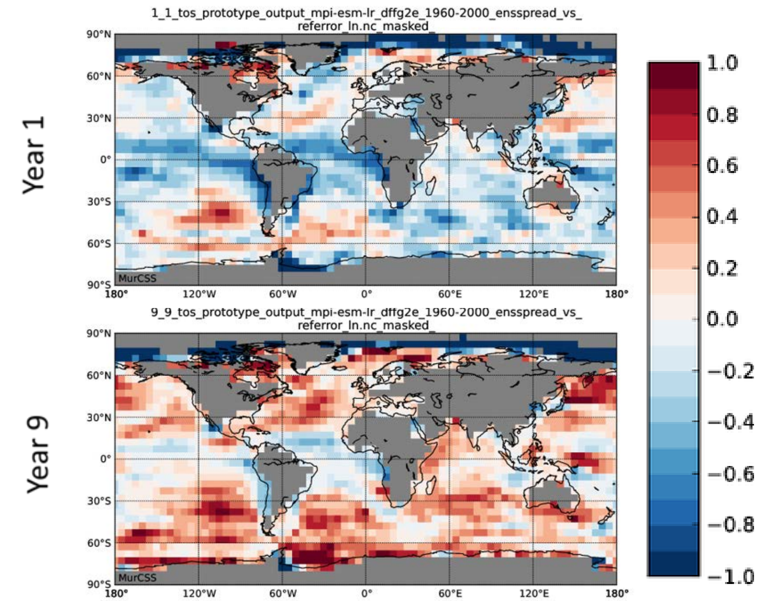
Spread-error ratio for SST



Ho et al., 2013

MiKlip-Prototype (MPI-ESM-LR)



MiKlip MURCSS tool, logarithmic ensemble spread score

- underdispersive (overconfident) ensemble spread at initial time
  - so far, few decadal prediction studies have represented the uncertainty in the 3D ocean initial state
- methods for perturbing the ocean state exist: *Hawkins and Sutton (2011); Zanna et al.; Tziperman and Ioannou (2002); Romanova and Hense (2015); etc.*

Ensemble generation methods (EGM) that aim to represent fastest growing errors

- Bred vectors *(e.g., MiKlip AODA-PENG ← Toth and Kalnay, 1993)*
- Singular vectors *(e.g., Hawkins and Sutton, 2011 ← Palmer et al., 1994; Molteni et al., 1996 and Kleeman et al., 2003 and others)*
  - optimized for maximum error growth and scaled to represent the analysis error
  - characterized by perturbation growth norm and optimization time
  - computationally expensive (SVs of a tangent propagator and adjoint of a dynamical system)

Ongoing projects that investigate EGMs for decadal prediction

- EU Project SPECS *(WP3.2 Improvements in ensemble generation)*
- German project MiKlip *(Module A, AODA-PENG)*

Recipe to generate oceanic singular-vector-based perturbations (OSVs)

1. Reduce the space (multivariate 3D EOFs; 28 PCs explain 68% of variance)

2. Fit a linear propagator to the PC time series (LIM) *following Penland and Matrosova (1994), and Penland and Sardeshmukh (1995):*

$$\frac{d\mathbf{x}}{dt} = \mathbf{Bx} + \mathbf{F};\ \mathbf{x}(t+\tau) = e^{\tau\mathbf{B}}\mathbf{x}(t) = \mathbf{G}(\tau)\mathbf{x}(t)$$

3. Singular vectors = eigenvectors of $\mathbf{G}(\tau)^T\mathbf{N}\mathbf{G}(\tau)$ under the quadratic (L_2) norm N and over optimization time τ=5 years:

$$\boldsymbol{\sigma}(\tau) = \frac{\|x(\tau)\|_N{}^2}{\|x(0)\|_N{}^2} = \frac{\mathbf{x}(0)^T\mathbf{G}(\tau)^T\mathbf{N}\mathbf{G}(\tau)\mathbf{x}(0)}{\mathbf{x}(0)^T\mathbf{x}(0)}$$

4. Phase-space rotation and scaling (to represent the RMSE pattern of the initial conditions taken from the GECCO2 synthesis) *following Molteni et al.*, 1996

5. Initial conditions = 4 SV that are added/subtracted from the unperturbed initial state

Marini C., Polkova I., Köhl A. and Stammer D. (2015, submitted to MWR)

Input for EOF: 3D annual temperature and salinity anomalies from the historical run

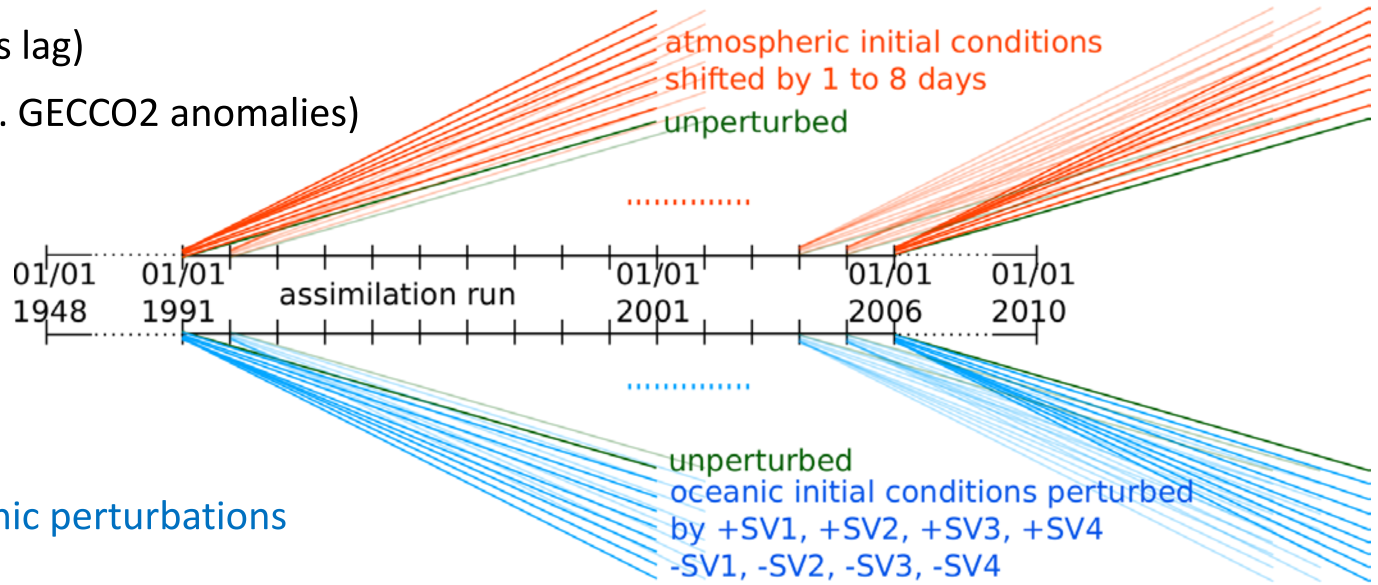
Experimental setup

1. Assimilation of GECCO2 anomalies in MPI Earth System Model (MPI-ESM-LR)

2. Two sets of ensemble hindcasts:

2a. Hindcasts based on atmos perturbations

- Initial conditions:
  - diff atmos state (1-8 days lag)
  - same ocean state (assim. GECCO2 anomalies)



2b. Hindcasts based on oceanic perturbations

- Initial conditions:
  - same atmos state
  - diff ocean state (assim. GECCO2 anomalies +/- perturbations)

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GECCO2 RMSE vs initial spread of OSV perturbations

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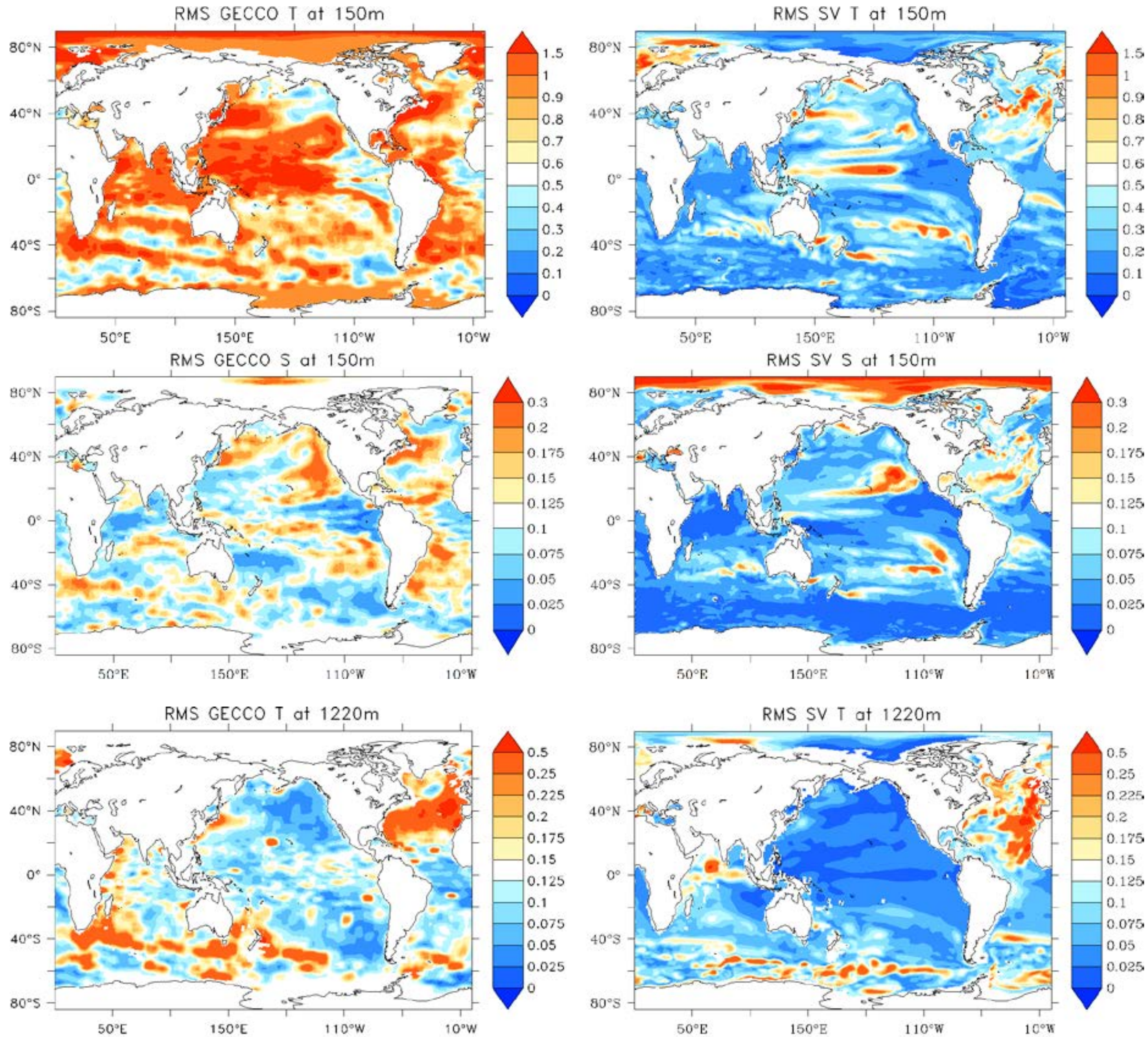
RMSE for GECCO2 is based on EN3 data over 2002-2011



Initial spread for temp perturbations 150 m

For salinity 150 m

For temp 1220 m

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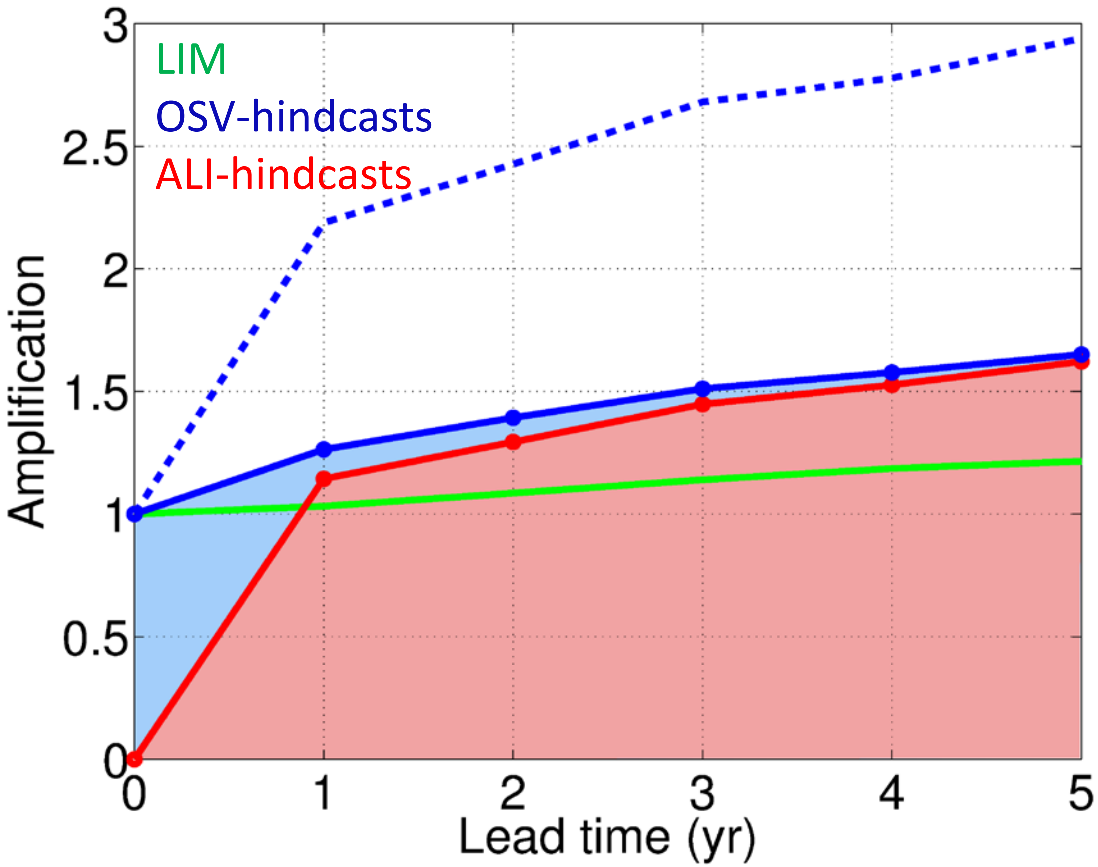
Amplification of global 3D oceanic perturbations (T,S) in a GCM



$$\sigma(t) = \sqrt{\frac{\|X'_i(t)\|^2}{\|SV_i\|^2}}$$

$$X'_i = X_{\text{perturbed}} - X_{\text{unperturbed}}$$

$$\sigma(t) = \sqrt{\frac{\|X'_i(t) \cdot nSV_i\|^2}{\|SV_i\|^2}}$$

$$nSV_i = \frac{SV_i}{\|SV_i\|^2}$$

i – ensemble member

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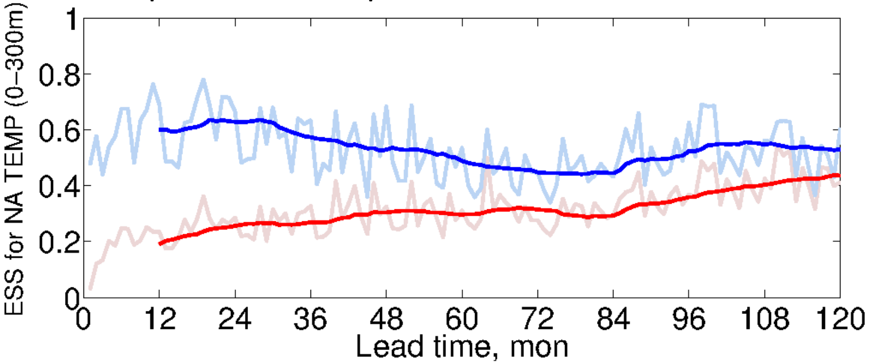
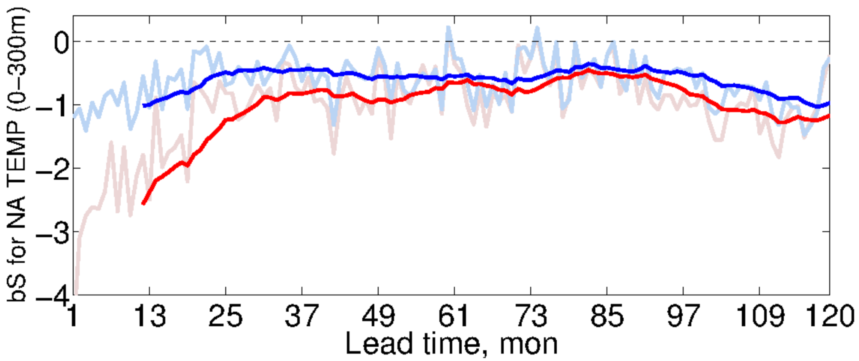
Spread scores for the North Atlantic subsurface ocean temperature (0-300m) based on EN3

ensemble spread score (ESS): reliability of spread with respect to error



beta score: reliability of spread with respect to obs. variability



OSV-hindcasts

ALI-hindcasts

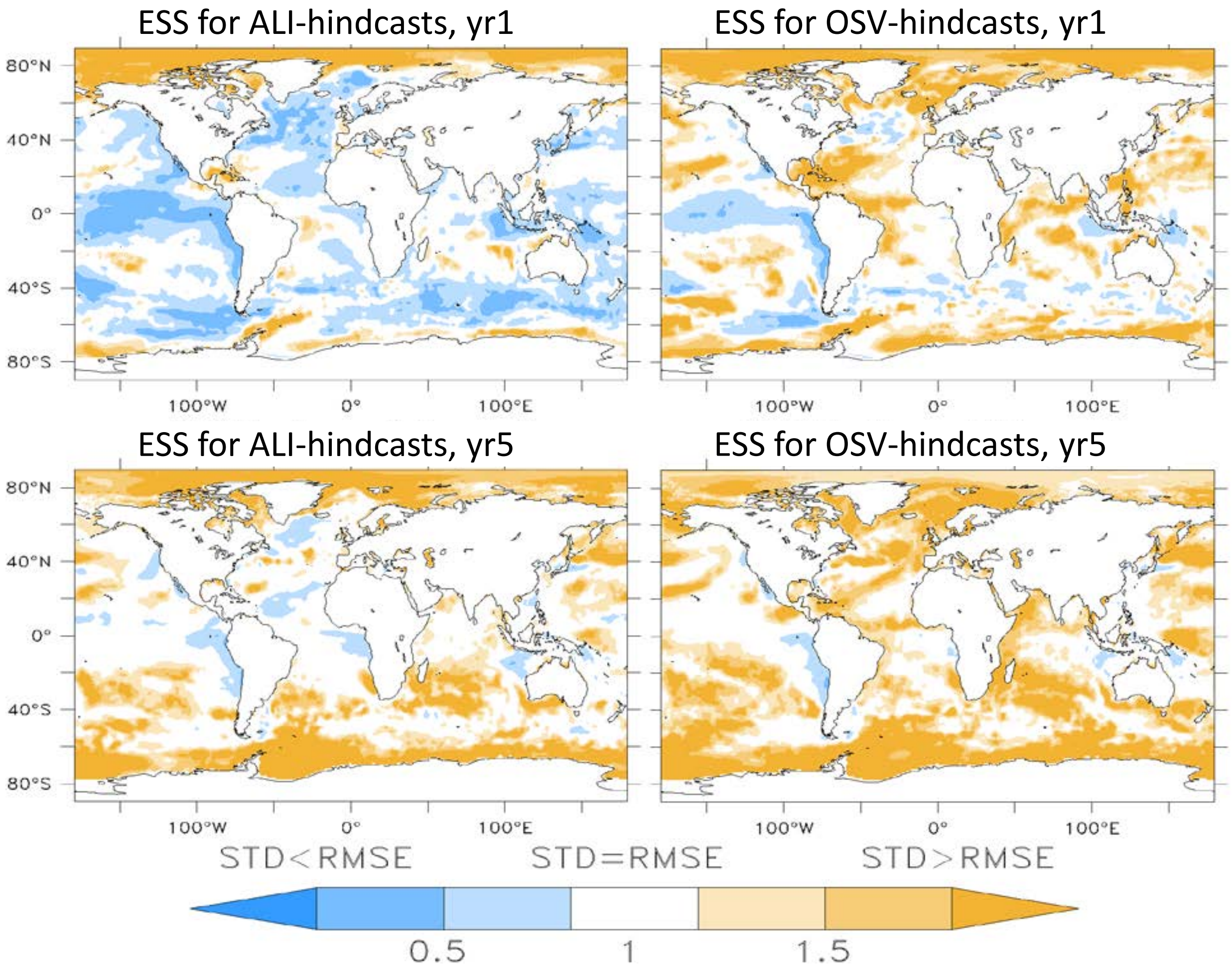
Overestimated spread ESS > 1, bS > 0

Underestimated spread ESS < 1, bS < 0

Perfect case ESS = 1, bS=0

Ensemble spread score for SST (leadtime: yr1 and yr5)

Verification dataset: HadISST

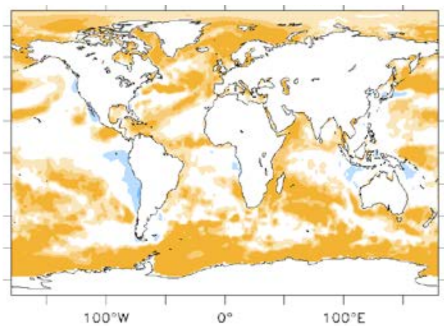


HadISST vs Reynolds SST

ratio of STD of the annual mean SST over 2003-2010

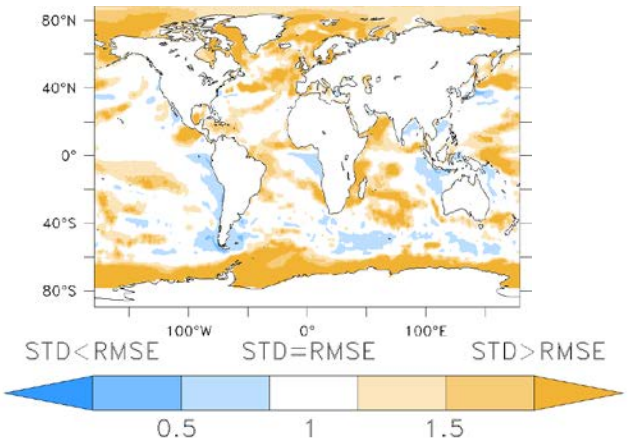
ESS for OSV-hindcasts, yr5

Based on HadISST

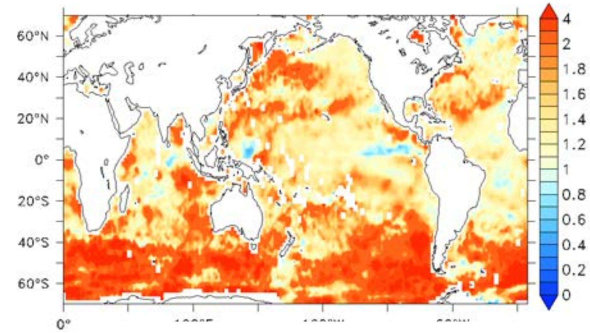


ESS for OSV-hindcasts, yr5

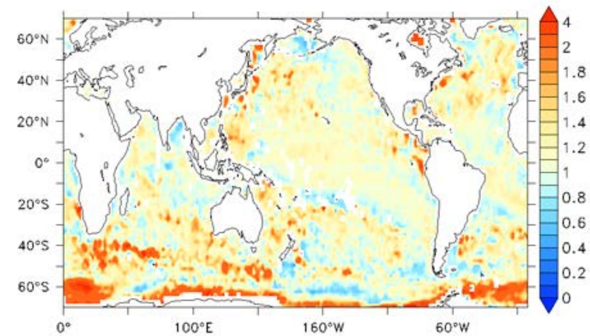
Based on Reynolds SST



AMSRE/HadISST



AMSRE/Reynolds

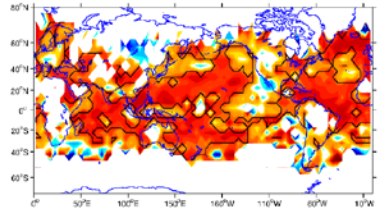


AMSR-E SST: data retrieved from observations of the satellite microwave radiometer “Advanced Microwave Scanning Radiometer” on-board of EOS

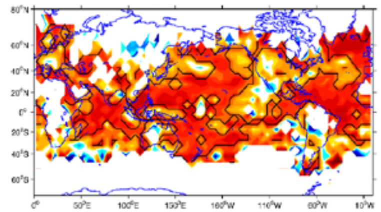
Correlation skill & skill score for SAT

Lead year 1:
55% of area - better skill for OSV

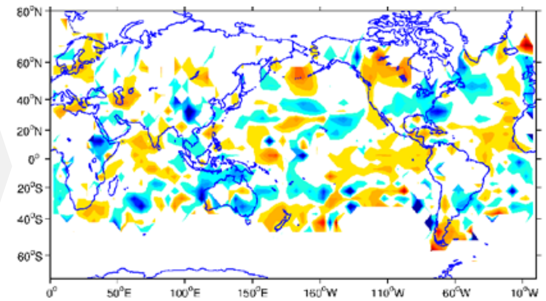
COR for ALI-hindcasts



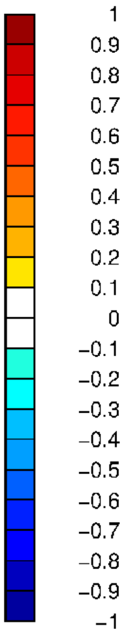
COR for OSV-hindcasts



Skill score: OSV vs ALI

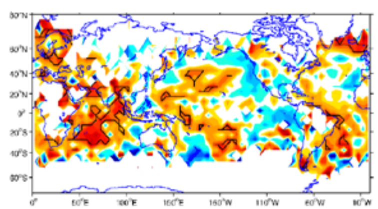


$$Skill\ score = \frac{COR^{OSV} - COR^{ALI}}{1 - COR^{ALI}}$$

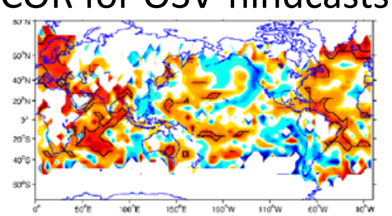


Lead year 5:
57% of area - better skill for OSV

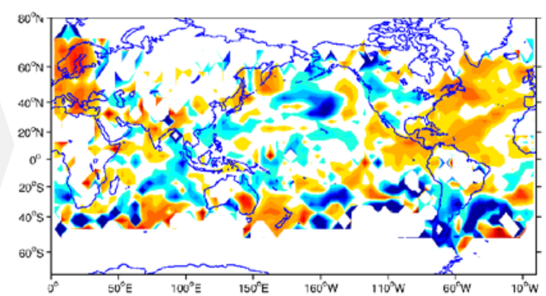
COR for ALI-hindcasts



COR for OSV-hindcasts



Skill score: OSV vs ALI



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Correlation skill over the North Atlantic

COR for ALI-hindcasts

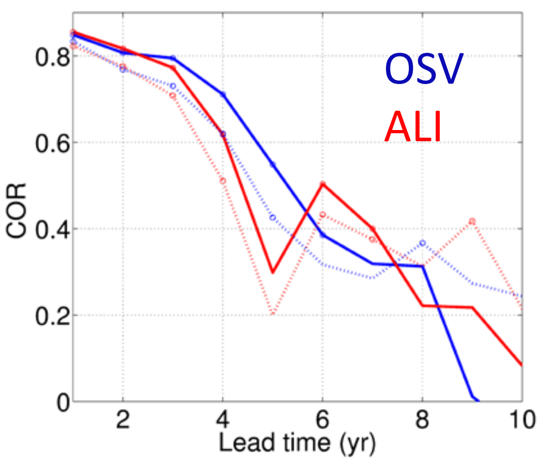
COR for OSV-hindcasts

Skill score: OSV vs ALI

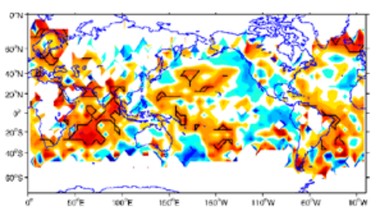
$$Skill\ score = \frac{COR^{OSV} - COR^{ALI}}{1 - COR^{ALI}}$$

Skill score: OSV vs ALI

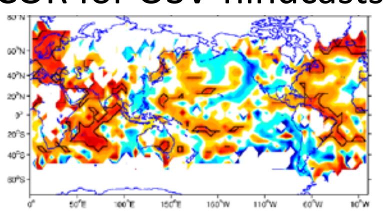
COR skill for
the North Atlantic SAT (solid)
and SST (dotted)



COR for ALI-hindcasts



COR for OSV-hindcasts



Predictive skill is based on HadCRUT3v
Hindcasts: not detrended, bias corrected

Summary

Does perturbing the ocean initial state improve the initial spread?

- LIM contributes to the growth of the ensemble spread
- OSV-based perturbations provide larger spread at the beginning of hindcasts, in contrast to atmospheric lagged initialization
- However:
  - most of the perturbation growth comes from the atmosphere
  - spread scores are shown to be sensitive to the choice of verification dataset

How is the predictive skill affected?

- The OSV method did not show much improvement for the predictive skill: about 55-57% of areas show an advantage of OSV over ALI for SAT, SST and OHC
- OSV-hindcasts show better skill over the North Atlantic

General comments to the OSV method

- Cheap method to calculate oceanic perturbations
- The OSV-method could possibly be improved with a different error scaling approach. Also different norms should be tested to get better amplification rates

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